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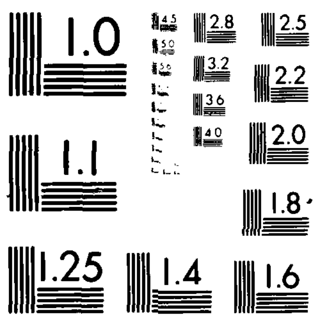

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Five techniques for determining annual water quality loadings were compared and evaluated according to data requirements, advantages and limitations, comparability of results, consistency of application, and technical personnel required. Recommendations were made concerning data collection in the field to characterize water quality loadings, such as suspended solids (SS), total Kjeldahl nitrogen (TKN), and total phosphorus (TP).

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20. ABSTRACT (Continued).

The techniques evaluated included two regional methods, Midwest Research Institute (MRI) and National Eutrophication Survey (NES). The three instream techniques evaluated were: average flow, average concentration ($\bar{Q}*\bar{C}$); flow-weighted concentration ($\overline{QC}$); and flow interval (FI). Regional methods required delineation of watershed land use, soil descriptions, and consultation with experts, e.g., U. S. Department of Agriculture-Soil Conservation Service, for coefficient selection. Instream techniques required streamflow and water quality data.

The agricultural Sandusky River and Honey Creek watersheds in Ohio and the forested Caddo River watershed in Arkansas were selected as prototypes for comparison of these techniques. Water quality parameters included in the study were SS, TKN, and TP. The results were used as input to a reservoir trophic status assessment procedure to compare their applicability to Corps of Engineers (CE) reservoir planning.

As a result of this study, it was concluded that the primary value of the MRI technique was to familiarize the user with the watershed's physiographic features and hydrologic response characteristics to better interpret water quality loading estimates. The NES method has only limited application, at best, to CE projects in selected geographical areas of the United States. The generalized regional methods for the most part were not adequate for estimating annual water quality loadings to reservoirs.

Of the three techniques that use available surface water quality and streamflow data, only the FI technique is statistically valid, and it is recommended for estimating annual water quality loadings to reservoirs based on the aforementioned evaluation factors. However, those water quality parameters that may load streams as a function of season and flow would require intensive sampling and analyses to statistically characterize the short-term loadings during the year. The $\bar{Q}*\bar{C}$ technique is applicable for water quality constituents that maintain fairly constant concentrations through the range of streamflow. The $\overline{QC}$ technique requires data representative of the flow range and runoff water quality characteristic of the watershed.

Field sampling programs for the purpose of estimating nonpoint source water quality loadings to reservoirs should include simultaneous measurement of flow and water quality to the reservoir. Samples should represent wide ranges of flow at different seasons of the year. Automatic water samplers that are activated by changes in flow velocity or river stage are recommended where extensive sampling is required.

PREFACE

This investigation was conducted as part of the U. S. Army Corps of Engineers Environmental and Water Quality Operational Studies (EWQOS) under Task ID.1. The EWQOS is sponsored by the Office, Chief of Engineers, and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, under the purview of the Environmental Laboratory (EL).

The study was conducted during the period October 1977 to September 1978 by Dr. H. E. Westerdahl, Mr. W. B. Ford III, Ms. J. Harris, and Dr. C. R. Lee, of the Ecological Effects and Regulatory Criteria Group, Ecosystem Research and Simulation Division (ERSD), EL. This study was under the direction of Dr. J. Mahloch, Program Manager of EWQOS, and under the general supervision of Dr. R. L. Eley, Chief, ERSD, and Dr. John Harrison, Chief, EL. The report was written by Dr. Westerdahl, Mr. Ford, Ms. Harris, and Dr. Lee.

Appreciation is expressed for manuscript review to Mr. L. Mulkey, Environmental Protection Agency, Athens, Georgia; Dr. M. Frere, U. S. Department of Agriculture (USDA)-Southern Regional Office, New Orleans, Louisiana; Dr. D. DeCoursey, USDA-Sedimentation Laboratory, Oxford, Mississippi; Mr. E. Lawson, U. S. Forest Service, Fayetteville, Arkansas; Mr. S. Ursic, U. S. Forest Service, Oxford, Mississippi; Messrs. M. Jennings and L. Land, U. S. Geological Survey, Bay St. Louis, Mississippi; and Dr. H. Pionke, UDSA-Science and Education Administration, University Park, Pennsylvania.

Commanders and Directors of WES during the study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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EVALUATION OF TECHNIQUES TO ESTIMATE ANNUAL WATER QUALITY LOADINGS TO RESERVOIRS

PART I: INTRODUCTION

Background

1. Surface runoff results in nonpoint source loadings of chemical constituents and suspended solids, which directly influence reservoir project purposes, management operations, and reservoir eutrophication. Over an extended period of time, the chemical and sediment contribution to the project from surface runoff and baseflow may change significantly as a result of the gradual process of watershed urbanization or major land use modifications. Hence, short- and long-term influence of watershed runoff on existing and proposed projects must be understood and predictable.

2. With existing technology, field personnel frequently have difficulty accurately assessing the influence of nonpoint source chemical and sediment loadings on the water quality of existing and proposed reservoir projects. Sufficient data, funding, and time usually are not available in early planning stages to allow Corps of Engineer (CE) personnel to apply existing simulation models, e.g. Hydrocomp International, Inc. (1976) and U. S. Army Hydrologic Engineering Center (1977).

3. The requirement for predicting water quality in proposed reservoirs, having been established by previous Public Laws and Executive Orders, has contributed to the development of several simplified techniques. These techniques require evaluation to determine which one provides estimates of annual loadings to reservoirs suitable for predicting long-term effects of nonpoint chemical and sediment loadings on reservoir water quality and eutrophication.

Purpose

4. The purpose of this study was to evaluate techniques most

commonly used by CE District personnel to estimate mean annual export rates of nonpoint source water quality constituents from watersheds of proposed and existing reservoirs.

Scope

5. This report presents comparative predictions of annual water quality loadings to reservoirs using techniques, exclusive of hydrologic and water quality modeling, most commonly used for planning by the CE District Offices. The techniques were used as they exist; no modifications or improvements were made. Since comparisons of techniques were made using existing field data, prototype watersheds were selected for which extensive stream water quality and streamflow data were readily available, including detailed land use, soil type, and resource management information. These included: (a) Caddo River watershed above Glenwood, Arkansas; (b) Sandusky River watershed above Fremont, Ohio; and (c) Honey Creek watershed above Melmore, Ohio. Detailed discussion of field sampling strategies was not within the scope of this report. Emphasis was placed on the application of each technique and the reasonableness of annual water quality loading predictions derived from the same field data and land use information for each prototype watershed.

Approach

6. After a review of numerous approaches for estimating loadings, e.g. Lystrom et al. (1978), True (1976), Wu and Ahlert (1978), Johnson et al. (1976), Fisher et al. (1968), and Biggar and Corey (1969), it was concluded that an interagency workshop should be held to select the approaches to be evaluated. In February 1978, this workshop was convened at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. Recommendations from the participants included evaluation of existing techniques and data requirements to predict annual loadings to reservoirs. In accord with these recommendations, five techniques for estimating the annual export rate of total phosphorus, total Kjeldahl

nitrogen, and suspended solids were selected. One technique was based on an empirically derived equation developed for the U. S. Environmental Protection Agency (EPA) by Midwest Research Institute (MRI) (McElroy et al. 1976). A regression technique developed by EPA's National Eutrophication Survey (NES) (Omernik 1977) was also selected. Additionally, three methods based on streamflow and referred to as instream techniques were chosen: average flow, average concentration ($\bar{Q}*\bar{C}$); flow-weighted concentration ($\overline{QC}$); and flow interval (FI). Evaluation criteria applied to these techniques included data requirements, necessity of local expertise, and relative consistency of predictions. Study objectives were to determine appropriate applications and to define specific advantages and limitations of each technique.

7. Since one of the primary uses of these techniques may be to estimate the annual loading of nutrients to reservoirs for subsequent use with simplified techniques for predicting trophic status, recommendations were included for the application of each technique for this purpose.

PART II: ANNUAL WATER QUALITY LOADING TECHNIQUES

8. Detailed descriptions of equations comprising each of the five techniques mentioned in paragraph 6 are given below. Specific data requirements, coefficients, and references are also included.

Midwest Research Institute

9. The objective of the MRI study was to develop procedures for estimating nonpoint pollutant sources primarily by using available information and local technical personnel.

10. The MRI Handbook (McElroy et al. 1976) includes regionalized loading functions and step-by-step procedures for their use. In addition, the Handbook: presents graphically and in tabular form some of the data required for application to watersheds throughout the United States; provides references to other data sources; and suggests simple methods for generating data when available data are considered inadequate. A loading function, as defined by the MRI Handbook, is a "mathematical expression to calculate the emission of a pollutant from a nonpoint source and discharge of the pollutant into surface waterways."

11. The basis for MRI loading functions is the Universal Soil Loss Equation (USLE), developed originally by W. H. Wischmeier (Wischmeier and Smith 1965) to describe the soil transport during sheet and rill erosion on small agricultural fields. The USLE expressed the amount of soil loss based on the soil type, slope length, crop management, and regional rainfall characteristics:*

$$Y(S) = \sum_{i=1}^{n} A_i \left(R \times K \times L \times S \times C \times P \times S_d\right)_i \tag{1}$$

* See the MRI Handbook, which contains appropriate figures and tables for selecting coefficients and necessary conversion factors from U. S. customary to metric (SI) units.

where

$Y(S)$ = annual yield of sediment from erosion to the stream, metric tons/yr

n = number of subareas in the watershed

A_i = acreage of watershed subarea i, ha

i = integer from 1 to n, where n = total number of subareas i in a watershed

R = rainfall erosivity factor (Figure 3-2, MRI Handbook), expressing the erosion potential of average annual rainfall in the locality. The R value is a summation of the individual storm products of the kinetic energy of rainfall and the maximum 30-min rainfall intensity, in cm/hr, for all significant storms, on an average annual basis

K = soil-erodibility factor, metric tons/ha for each R unit

L = slope-length factor, dimensionless

S = slope-steepness factor, dimensionless

C = cover factor, dimensionless

P = erosion control practice factor, dimensionless

S_d = sediment delivery ratio, dimensionless

12. In addition to sediment load from erosion, MRI has developed functions and data requirements that depend on USLE output to predict the export rate of total nitrogen and total phosphorus, available nitrogen and phosphorus, pesticides, organic matter, heavy metals, traffic-related pollutants, and acid-mine drainage.

13. Total nitrogen load has two components: nitrogen associated with the sediment load and nitrogen input from rainfall.* Nitrogen load can be determined by:

$$Y(N)_{Pr} = A \times \frac{Q(OR)}{Q(Pr)} \times N_{Pr} \times b \quad (2)$$

where

$Y(N)_{Pr}$ = stream nitrogen load from precipitation, kg/yr

A = area, ha

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* See the MRI Handbook, which contains appropriate figures and tables for selecting coefficients and necessary conversion factors from U. S. customary to metric (SI) units.

$Q(OR)$ = overland flow from precipitation, cm/yr

$Q(Pr)$ = total amount of rainfall, cm/yr

N_{Pr} = nitrogen load in precipitation, kg/ha/yr

b = attenuation factor, dimensionless

The total nitrogen loading from erosion $Y(NT)_e$ is estimated by:

$$Y(NT)_e = a \times Y(S)_e \times C_s(NT) \times r_n \tag{3}$$

where

a = dimensional constant

$Y(S)_e$ = total sediment load, kg/yr

$C_s(NT)$ = amount of nitrogen in the top 30 cm of soil, g/100 g
$= 0.55e^{-0.08T}\,(1 - e^{-0.005H})$

T = annual average temperature, °C

H = humidity factor, dimensionless

and

$$H = \frac{Pr}{\left(1 - \frac{RH}{100}\right) SVP_t} \tag{4}$$

where

Pr = precipitation, cm/yr

RH = relative humidity, percent

SVP_t = saturated vapor pressure at given temperature, mm of Hg

r_n = nitrogen enrichment ratio, dimensionless

Total phosphorus load is estimated by

$$Y(PT) = a \times Y(S)_e \times C_s(PT) \times r_p \tag{5}$$

where

$Y(PT)$ = total phosphorus load to the stream, kg/yr

$C_s(PT)$ = amount of phosphorus in the top 30 cm of soil, g/100 g

r_p = phosphorus enrichment factor, dimensionless

14. The MRI Handbook includes appropriate figures and tables to determine all of the coefficients, given the watershed characteristics. These characteristics should be described by personnel familiar with the watershed soils, land use, and hydrology. This is recommended in preference to the watershed descriptions provided within the MRI Handbook or the U. S. Geological Survey (USGS) National Atlas (USGS 1970). Geographical variability between watersheds within the same region of the country is not represented in the MRI Handbook and National Atlas on a scale commensurate with CE planning requirements for reservoirs. The MRI Handbook is based on data from first-order watersheds, whereas the National Atlas describes regional areas, e.g., major river basins.

National Eutrophication Survey

15. The EPA conducted a nationwide sampling program to survey this country's lakes, reservoirs, and tributaries for the purpose of providing a measure of their trophic status. Based on the sampling of more than 4000 NES tributaries, 928 were found to meet the nonpoint source criterion for developing a nonpoint source loading relationship. Each watershed was sampled once a month for a year. However, the sampling program extended over a 3-year period: 133 sites were sampled in the northeast during 1972; 340 sites were sampled in the east and southeast during 1973; and 455 sites were sampled in the west and midwest during 1974. At the EPA laboratory in Corvallis, Oregon, J. M. Omernik (1977) developed regional regression equations for lakes and reservoirs by relating watershed location, land use, and streamflow to their loading rates of phosphorus and nitrogen. The information required for this method included the general location of the watershed and the percent land use of the watershed classified as forest, cropland, and urban.

16. Initially, each regression equation was developed using characteristics that were thought to influence instream nutrient levels, e.g., soil geology and land use. However, it was found that land use

was the watershed characteristic that correlated closer to stream nutrient concentrations. Data were analyzed with respect to the eastern, central, and western regions of the country. Equations are listed in Table 1 for the regional regression analyses of nitrogen and phosphorus and related interpretive factors.

17. The NES regression equation estimates a mean annual concentration. For any time period for which a loading value is required, the stream discharge must be known to convert the mean annual concentration to an export rate.

18. From Table 1, the range of nutrient concentrations can be determined by the equation:

$$\text{Range} = \frac{f \times r}{\log_{10} \text{nutrient concentration}} \tag{6}$$

where

f = multiplicative standard error

r = correlation coefficient

$\log_{10}$ nutrient concentration = value estimated by equation

The range (Equation 6) was found to contain approximately two thirds of the observed nutrient concentrations for a given land use combination. A first approximation of the mean annual concentration, using only the land use information for a selected watershed, can be obtained from the NES regional graphs (Figures 23 and 24, NES Handbook). In addition, the procedure allows for refining the first approximation by geographical area when nutrient concentrations are expected to vary from the predicted value (Figures 25-28, NES Handbook (Omernik 1977)). A more refined estimate of the mean annual nutrient concentration can be obtained by the equation:

$$\text{Mean annual concentration} = \sigma \times \log_{10} f + \log_{10} \text{nutrient concentration (from Table 1)} \tag{7}$$

Table 1

NES Stream Nutrient Concentration Predictive Models (from Omernik 1977)

Region	Model, Correlation Coefficient, and Multiplicative Standard Error
	Total Phosphorus
East	Log_{10} (PCONC) = 1.8364 + 0.00971 (% agric + % urb) r = 0.74, f = 1.85
Central	Log_{10} (PCONC) = -1.5697 + 0.00811 (% agric + % urb) -0.002312 (% for) r = 0.70, f = 2.05
West	Log_{10} (PCONC) = 1.1504 + 0.00460 (% agric + % urb) -0.00632 (% for) r = 0.70, f = 1.91
	Orthophosphorus
East	Log_{10} (OPCONC) = -2.2219 + 0.00934 (% agric + % urb) r = 0.73, f = 1.86
Central	Log_{10} (OPCONC) = -2.0815 + 0.00868 (% agric + % urb) r = 0.63, f = 2.05
West	Log_{10} (OPCONC) = -1.5513 + 0.00510 (% agric + % urb) -0.00476 (% for) r = 0.64, f = 1.91
	Total Nitrogen
East	Log_{10} (NCONC) = -0.08557 + 0.00716 (% agric + % urb) -0.00227 (% for) r = 0.85, f = 1.51
Central	Log_{10} (NCONC) = -0.01609 + 0.00399 (% agric + % urb) -0.00306 (% for) r = 0.77, f = 1.50
West	Log_{10} (NCONC) = -0.03665 + 0.00425 (% agric + % urb) -0.00376 (% for) r = 0.61, f = 1.75
	Inorganic Nitrogen
East	Log_{10} (INCONC) = -0.3479 + 0.00858 (% agric + % urb) -0.00584 (% for) r = 0.84, f = 1.93
Central	Log_{10} (INCONC) = -0.5219 + 0.00482 (% agric + % urb) -0.00572 (% for) r = 0.71, f = 2.06
West	Log_{10} (INCONC) = -0.6339 + 0.00789 (% agric + % urb) -0.00657 (% for) r = 0.65, f = 2.45

where σ = standard deviation for a specific geographic area (Figures 25-27, NES Handbook)

19. An annual export rate for a specific nutrient can be estimated as

$$\text{metric tons/yr} = C \times 31.536 \times F \tag{8}$$

where

C = mean annual concentration, mg/ℓ

31.536 = dimensional constant

F = mean annual flow, cu m/sec/yr

20. Omernik (1977) stated that the relationships indicate correlations only between existing land use patterns and stream nutrient concentrations. These factors were thought to explain why there was a difference in the correlation coefficient for each of the models describing nutrient concentrations in streams from the three regions of the country. Land use patterns in the western region were considered significantly less disturbed by man than the eastern region. Hence, the correlation coefficient was higher for the eastern region than for either of the other two regions. Predictions of loadings using these regression equations are not considered valid if land use patterns have changed significantly since completion of the NES.

Average Flow, Average Concentration

21. This approach represented perhaps the simplest instream method for computing annual loadings of water quality constituents. The mean concentration $\bar{C}$ of a given constituent was determined using all available water quality data i collected on a given stream or river.

$$\bar{C} = \frac{\sum_{i=1}^{n} C_i}{n} \tag{9}$$

where

$\bar{C}$ = mean concentration, mg/ℓ

i = an integer from 1 to n

n = number of measurements

C_i = measured concentration for each data measurement i , mg/ℓ

The mean flow $\bar{Q}$ was determined using all available flow data i on a given stream or river:

$$\bar{Q} = \frac{\sum_{i=1}^{n} Q_i}{n} \tag{10}$$

where

$\bar{Q}$ = mean flow, cu m/sec

Q_i = flow of each data measurement i , cu m/sec

The product of Equations 9 and 10, $\bar{Q}*\bar{C}$, represents an average loading rate over a year, expressed as a function of watershed area. This is considered to be an estimate of the annual export rate, i.e., kilograms per hectare per year. The data required for this method are usually available in the CE Districts and EPA's STORET (U. S. EPA 1979) nationwide computer library of water quality and quantity data for inland waters.

Flow-Weighted Concentration

22. Flow-weighted loadings $\overline{QC}$ were considered essentially as average loading rates. Each pair of flow Q_j and concentration C_j data is multiplied to express a loading rate as mass per unit time. Next, these loading rates are summed over the data set and divided by the number of values n :

$$\overline{QC} = \frac{\sum_{j=1}^{n} (Q_j C_j)}{n} \tag{11}$$

where

j = each data pair

n = number of values within the data set for which flow and concentration values have been recorded simultaneously

$Q_j C_j$ = *product of flow and concentration*, mg/cu m × unit time

The annual export rate is expressed as $\overline{QC}$ summed over a year and expressed as a function of the watershed area, i.e., kilograms per hectare per year.

Flow Interval

23. Initially, the flow interval (FI) method was developed in the Lake Erie Wastewater Management Study (U. S. Army Engineer District, Buffalo 1975) to estimate the phosphorus loading contributed to the lake from watersheds with little or no water quality data. Generally, as developed, the method should be considered applicable to any flow-dependent water quality constituent of interest. It requires constituent concentration measurements and instantaneous flow data (or daily flow records) that are usually available from the USGS District Offices or CE District Offices. The annual water quality loading is determined by plotting the product of a constituent concentration times the flow rate at the time of sampling, i.e., discrete flux measurement, versus flow for the period of record. Next, the number of flow intervals is arbitrarily determined at n and the flow rate Q_i at the end of each interval is given as follows:

$$Q_i = \frac{Q_{max}}{n} \tag{12}$$

where

Q_i = flow, cu m/sec, at the end of each interval i

i = flow interval

Q_{max} = largest measured flow, cu m/sec

n = number of flow intervals

24. For each flow interval i, *the mean flux* $\bar{L}_i$ is determined

as well as the standard error of the mean s_i^2 :

$$\bar{L}_i = \frac{\sum_{i=1}^{k} L_i}{k} \tag{13}$$

and

$$s_i^2 = \frac{\sum_{i=1}^{k} (L_i - \bar{L}_i)^2}{k(k-1)} \tag{14}$$

where

L_i = discrete flux measurements within the flow interval Q_i , mg/cu m/sec

k = number of flux measurements

The mean flux $\bar{L}$ for the period of record is

$$\bar{L} = \sum_{i=1}^{n} \bar{L}_i P_i \tag{15}$$

and the variance V is

$$V = \sum_{i=1}^{n} s_i^2 P_i^2 \tag{16}$$

where

P_i = probability of a given flow occurring in flow interval i is determined from the available flow record by

$$P_i = \frac{d_i}{D} \tag{17}$$

d_i = number of sampling times in which flows in interval i occurred

D = total number of sampling times in the period under consideration

The range of values for the average flux per unit time L for a given constituent is

$$L = \bar{L} \pm k_s \sqrt{V} \tag{18}$$

where

k_s = 1.645 at a 90 percent confidence interval assuming a normal distribution

For an annual water quality export rate L_A, the average flux $\bar{L}$ is multiplied by the appropriate time period t to convert $\bar{L}$ to average flux per year:

$$L_A = t \times \bar{L} \tag{19}$$

The annual water quality export rate L_A represents a probabilistic flow-weighted estimate for the time period over which the data were collected.

PART III: SELECTION OF STUDY WATERSHEDS

25. The following description of each watershed contains the information required to apply and evaluate the MRI and the NES regional loading methods. Instream methods only require water quality and flow records; however, interpretation of the loading estimates may require watershed information similar to that for the regional methods.

26. Existing data sets for nonpoint source water quality loadings from both forested and agricultural watersheds were used for evaluating the selected loading techniques. The primary criteria were availability of: comprehensive data including physiographic features of the watershed; flow records; and, water quality parameters of suspended solids, total phosphorus, and total nitrogen.

27. The selected watersheds represented a range of nonpoint sources for water quality constituents. Included were the forested Caddo River watershed in west central Arkansas and the agricultural watersheds of the Sandusky River and Honey Creek within the Lake Erie Basin in north central Ohio.

Sandusky River Watershed*

28. The Sandusky River is approximately 185 km long and drains approximately 368,000 ha of intensively cultivated agricultural land in north central Ohio (Figure 1). The river channel shows numerous meanders and flows through glacial till material. The channel slope ranges from less than a 0.4-m/km drop to a 4.7-m/km drop below Tiffin, Ohio. Sidewalls of the channel are subject to sloughing during elevated flow conditions. The historical flow and water quality records (U. S. Army Engineer District, Buffalo 1978) represent an extensive data collection effort at the Fremont, Ohio, stream gage.

29. The Till Plain encompasses the southern 65 percent of the

* Descriptions of the Sandusky River and Honey Creek watersheds were provided by the U. S. Army Engineer District, Buffalo (1975).

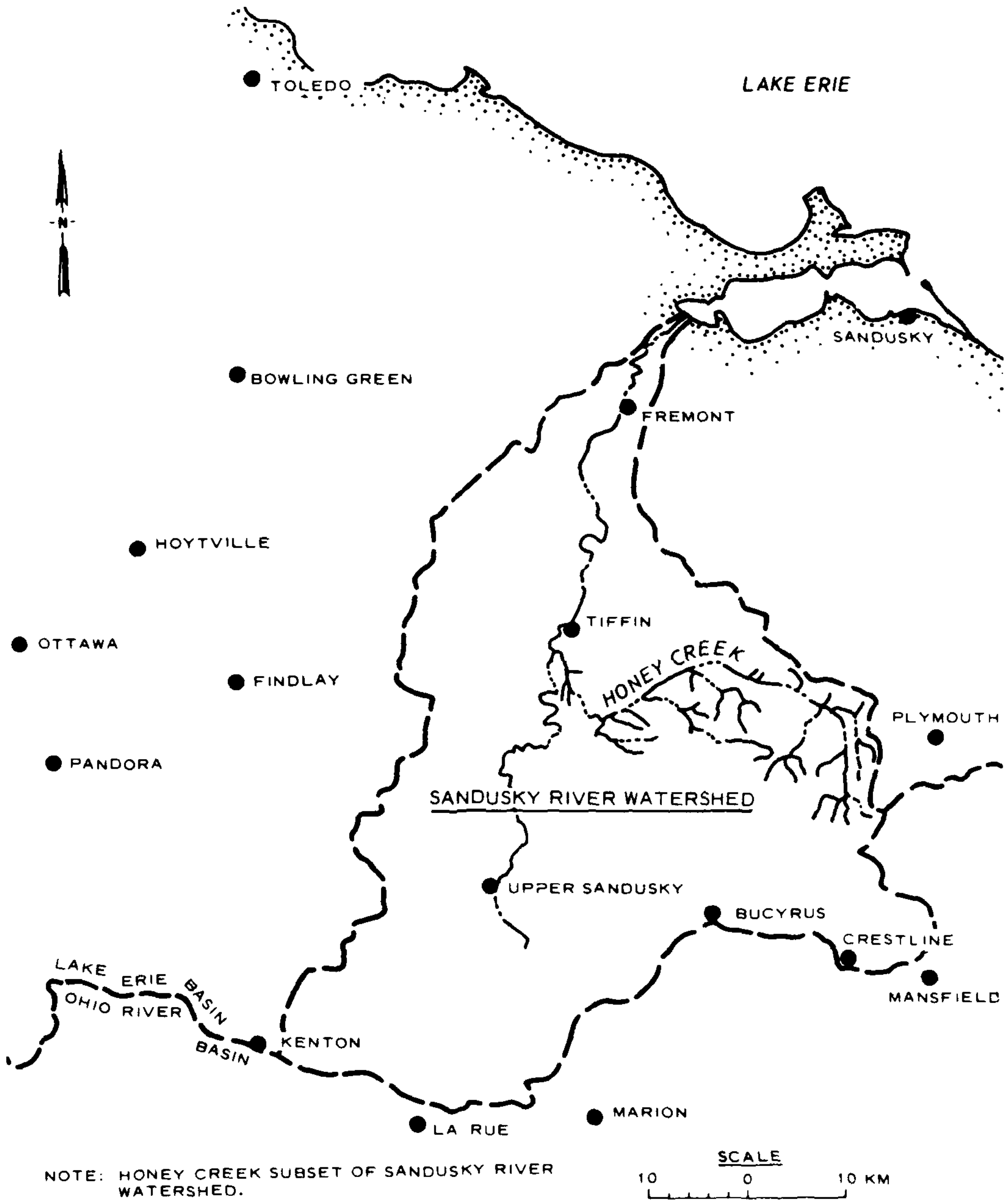

Figure 1. Sandusky River watershed in north central Ohio (from U. S. Army Engineer District, Buffalo 1975)

watershed and a low east-west trending moraine crosses the watershed just south of Tiffin, Ohio. The northern 35 percent of the watershed is located within the Lake Plains subprovince. The surface bedrock formations consist primarily of limestone, dolomite, and shale. The presence of groundwater storage is small since the formations are characteristically dense. Glacial drift and lake deposits are thin and of very low permeability. Near Bucyrus, Crestline, and Upper Sandusky, the glacial drift is highly permeable and thicker in the vicinity of the moraines.

30. Glacial deposits resulted in the development of very complex soil types with a variable texture. In the northern 35 percent of the watershed, the soils are predominantly the very poorly drained Hoytville silty clay loam and clay. In the southern 65 percent of the watershed, the soils are moderately fine-textured Wisconsin glacial till. The western part of the Till Plains consists of soils developed over limestone, whereas the soils in the eastern portion are underlain by sandstone and shale. The groundwater contribution to streamflow is quite small with a low sustained flow. However, the agricultural land in the western portion of the watershed has been made productive only through provision of underground tile drainage to allow more productive farming.

31. Very detailed land use, soils, and topographic information were provided through computer analysis of high altitude aerial photographic imagery. This information was developed as part of the Buffalo District's Lake Erie Wastewater Management Study (U. S. Army Engineer District, Buffalo 1975). A subsequent project (Cahill, Pierson, and Cohen 1978), concerning evaluation of best management practices, as demonstrated on the Honey Creek watershed, contributed to this very detailed data set describing land use and soils. The study area represented about 3,200 sq km above the city of Fremont, Ohio, and the USGS gage. Of the approximately 320,000 ha included in this study, 256,200 ha (80 percent) is comprised of cropland; 7,300 ha (2 percent) is pasture; 28,700 ha (9 percent) is urban; 21,400 ha (7 percent) is forest; and the remaining 6,400 ha (2 percent) is surface water. Major crops include corn, soybeans, and wheat. Approximately 200,000 people reside in this watershed.

Honey Creek Watershed*

32. Honey Creek is a tributary to the Sandusky River (Figure 2). Approximately 48,400 ha is drained by this creek. The channel is 72 km long and slopes an average of 3 m/km. The existing data file reflects 39,100 ha of watershed above the Melmore, Ohio, stream gage. The historical flow and water quality data collection was initiated in 1976. The data include numerous elevated flow sampling and water quality analyses of samples obtained every 4 hr.

33. Soil mapping of this watershed was completed by the U. S. Department of Agriculture (USDA) Soil Conservation Service (SCS) and the Ohio Department of Natural Resources. The soils are fine textured although quite variable, e.g., muck to sand. The watershed lies in the glacial till region of the Sandusky River watershed; hence, the soils have low permeability and very poor natural drainage. The seasonal water table is within 15 cm of the land surface for approximately 82 percent of the area. Approximately 80 percent of the land has less than 2 percent slope and only 4 percent of the land has a slope greater than 6 percent. An important characteristic of the soils is their inherently high erodibility coupled with long slope lengths to a channel.

34. Tile drainage systems are in use throughout the watershed to increase field drainage and enable mechanized fieldwork earlier in the spring and later in the fall.

35. Of the 39,100 ha total area, 31,800 ha (81 percent) is cropland. Major crops include corn, soybeans, and wheat. Approximately 4,200 ha (11 percent) is forested, 2,000 ha (5 percent) is urban, 800 ha (2 percent) is wetlands, and 300 ha (1 percent) is water.

Caddo River Watershed

36. The Caddo River watershed is in west central Arkansas

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* The description of the Honey Creek watershed was provided by the U. S. Army Engineer District, Buffalo (1975).

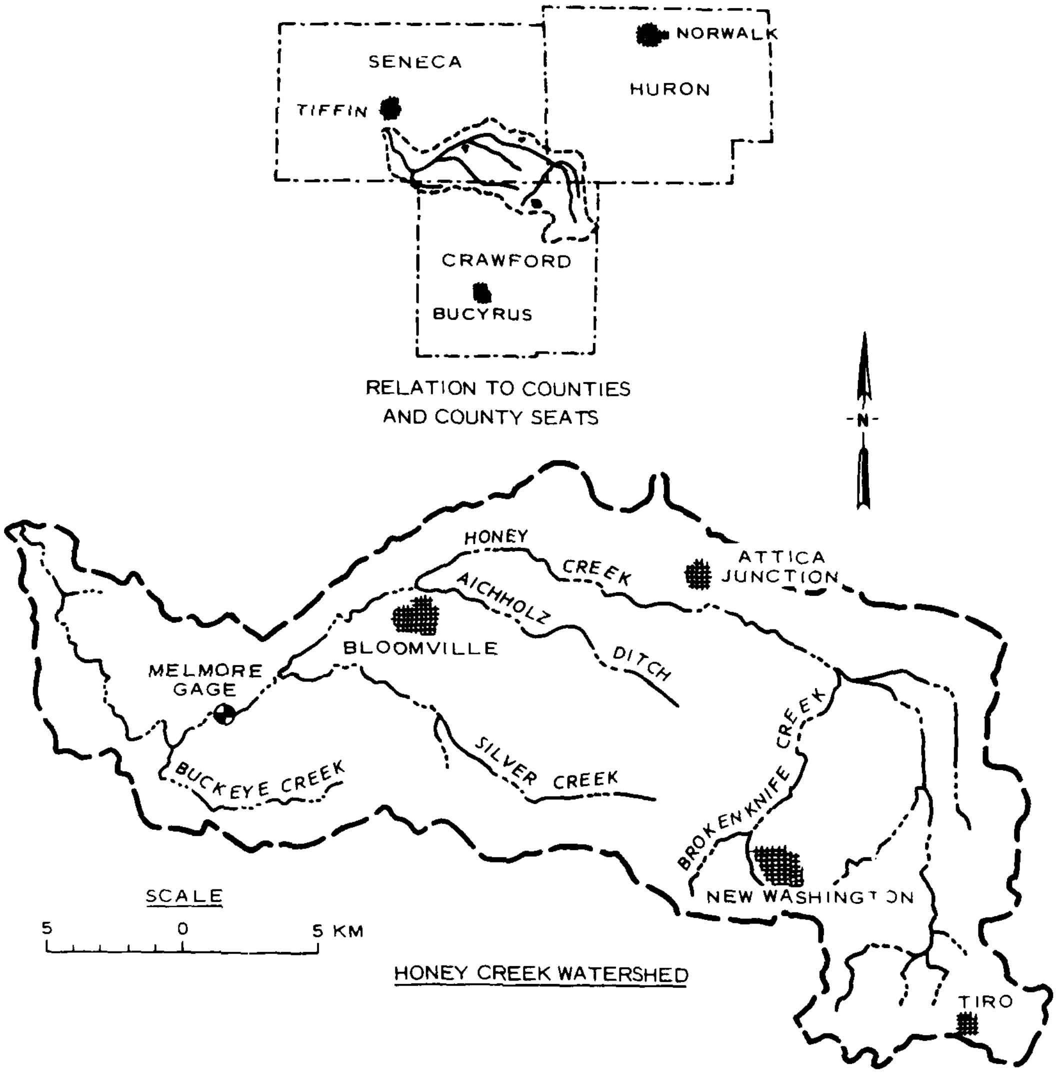

Figure 2. Honey Creek watershed in north central Ohio (from U. S. Army Engineer District, Buffalo 1975)

(Figure 3). The river flows a distance of 126 km from its source in the Ouachita Mountains to its confluence with the Ouachita River. The watershed has an area of 117,600 ha with an elevation range from 675 m in the mountains on the west to 53 m in the east at the confluence with the Ouachita River.

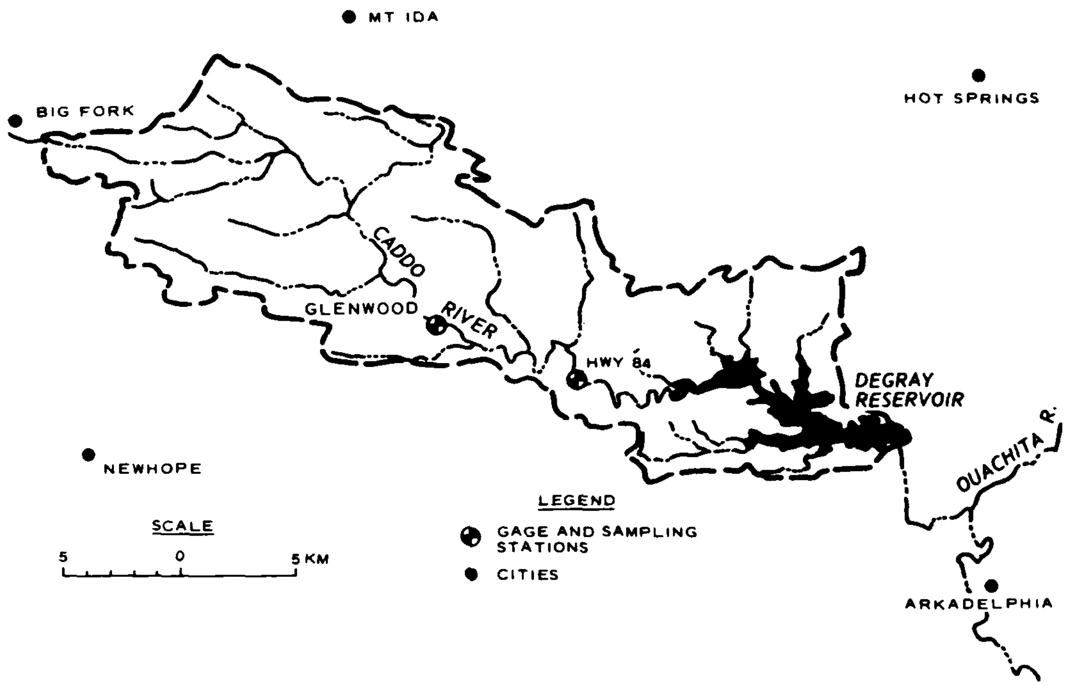

Figure 3. Caddo River, Arkansas, watershed showing Glenwood gage

37. The headwaters region of about 52,000 ha lies to the west-northwest of Glenwood, Arkansas, and is part of the Novaculite Uplift. This region is composed of long, eastward-trending, even-crested mountains and flat intermountain basins. The region is underlain by mixtures of shale and sandstone rocks. However, some chert is observable on the south side of the watershed with a few outcrops on the north side.

38. West of Glenwood, Arkansas, the dominant soil associations are the Carnasaw, Pickens, and Pickwick. The Pickens soils are found

on steep mountains and ridges. They are characterized as very shallow, acid, excessively drained, and moderately permeable loamy soils with considerable gravel. The Carnasaw soils are found on rolling hills and are moderately deep, acid, and well drained. They are derived from a quartzite and sandstone bedrock with an overlying clay loam subsoil. The Pickwick soils are found near the streambanks and are typically deep, acid, and well drained with a lot of gravel near the surface.

39. Forested land occupies more than 80,000 ha (68 percent) of the watershed with oak, hickory, and pine being the dominant species. Agriculture occupies about 35,300 ha (30 percent) of the watershed and consists of pastures, hay meadows, and abandoned fields in varying stages of succession. The remaining 2 percent of the watershed area is urban and developed land with a population estimated to be less than 1500 people.

40. The climate of the watershed is generally mild. Summers are quite long with temperatures occasionally greater than 40°C, and winters are usually short and moderate. Average annual precipitation is 135 cm with 43 percent of the precipitation resulting in runoff.

41. Runoff tends to be higher in the headwater portion of the watershed west of Glenwood, Arkansas. This portion of the watershed, which comprises only 44 percent of the total area, contributes over 60 percent of streamflow. The stream gage at Glenwood, Arkansas, was selected for this study since it had the best historical flow record (26 years) and several years of water quality data.

42. The peak discharge frequency curve for the Caddo River at the Glenwood gage is shown in Figure 4. The mean annual peak storm flow, interpolated from this curve, is about 500 cu m/sec. The range of annual peak flows during the period of record, 1940-1976, was from 2500 cu m/sec in 1968 to 80 cu m/sec in 1941, which corresponds to water depths of approximately 10 m and 3 m, respectively, at the Glenwood gage.

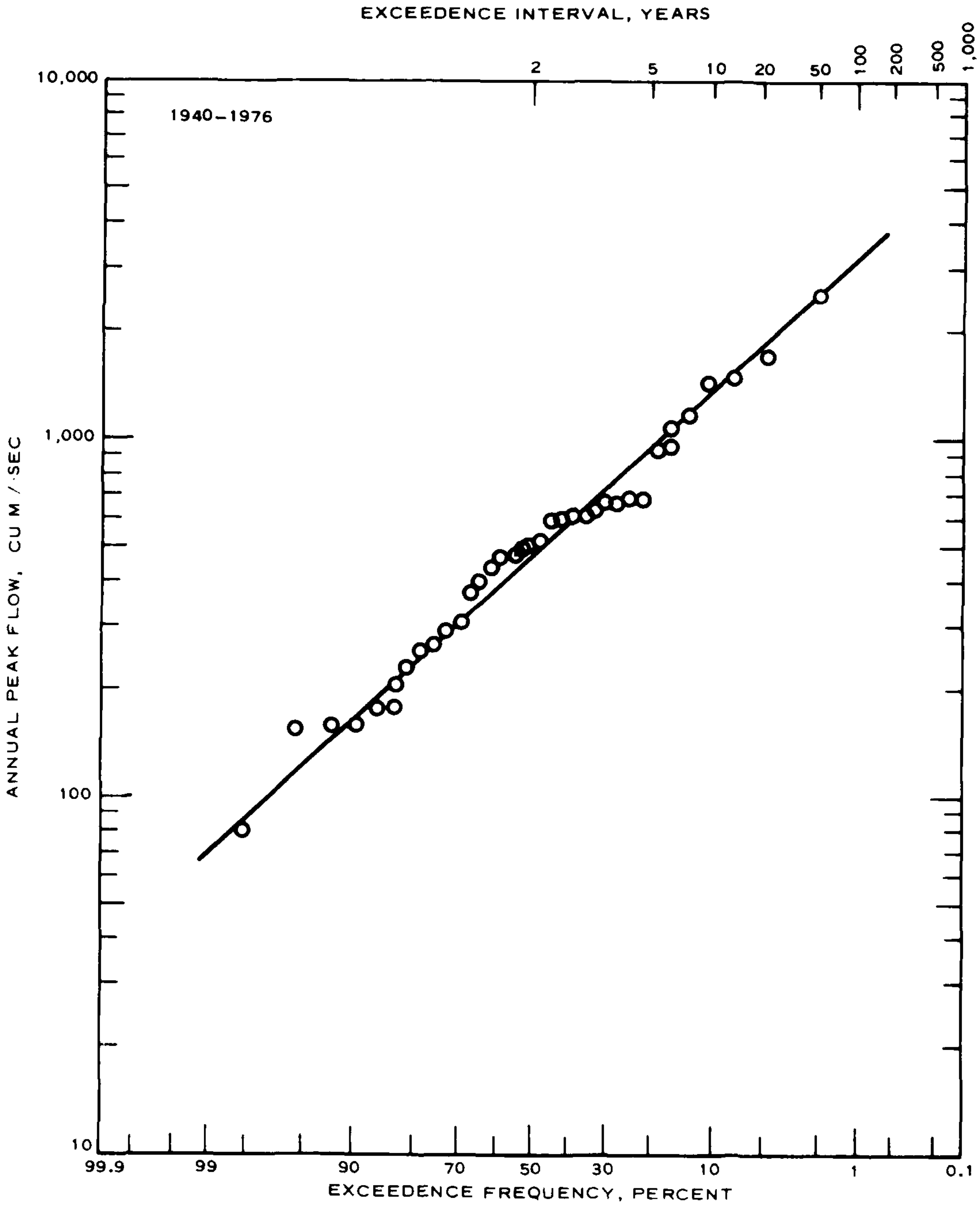

Figure 4. Annual peak flow occurrence on the Caddo River at the Glenwood gaging station for 1940-1976

PART IV: APPLICATION AND COMPARISON OF TECHNIQUES FOR COMPUTING NONPOINT SOURCE ANNUAL WATER QUALITY EXPORT RATES

Introduction

43. The data requirements, ease of application, and assumptions and limitations characteristic of each technique are described in this section. Techniques were categorized as follows: (a) those regionalized techniques requiring physiographic information about the watershed, and (b) those techniques that require instream water quality and flow measurements. Regionalized techniques included MRI (McElroy et al. 1976) and NES (Omernik 1977). Instream techniques included the average flow, average concentration ($\bar{Q}*\bar{C}$); flow-weighted concentration ($\overline{QC}$); and flow interval (FI). Comparison of these techniques using identical data sets provides the information required to objectively select the technique(s) most suitable for a specific application.

44. Comparison and evaluation of results within the regionalized techniques category emphasized the following: (a) quantity and detail of land use, soil, and meteorological information required; (b) optimum watershed size for its application; (c) type of watershed for best application, i.e., forested or agricultural; and (d) assumptions and limitations of the techniques. These topics were addressed by comparing effects of the physiographic information requirements on the estimated annual water quality export rate for the Caddo River watershed. The first evaluation used only general physiographic information found in the Phase I General Design Memorandum (U. S. Army Engineer District, Vicksburg 1966) for the DeGray Lake; the second evaluation included very detailed land use, soil, and topographic analyses that had been completed from a previous investigation.* The assumptions and limitations

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* J. Nix et al. 1974. "Collection of Environmental and Water Quality Data on DeGray Lake and Caddo River Watershed" (unpublished), Annual Contract Report, prepared by Arkansas Water Resources Research Center, Fayetteville, Ark., for U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., under Contract No. DACW39-73-C-0125; reports prepared in 1975, 1976, and 1977 under Contract No. DACW39-75-C-0025.

associated with the NES and MRI techniques were discussed to determine the applicability of each technique to forested and agricultural watersheds.

45. The instream techniques category was evaluated based on adequacy of historical flow and water quality records, sampling frequency, and advantages and limitations associated with their application. These techniques were used to estimate annual export rates, using available flow and water quality data for each watershed.

Midwest Research Institute

46. The MRI Handbook provided a step-by-step procedure with guidance on specific data requirements for determining mean annual export rates of a variety of pollutants from nonpoint sources. The MRI procedures evaluated in this study included: annual soil loss by erosion to waterways, total phosphorus (TP) annual export rate, and total nitrogen annual export rate. For this evaluation, total Kjeldahl nitrogen (TKN) was defined as the MRI's total nitrogen minus nitrate-nitrogen and nitrite-nitrogen values. As previously stated, all export rates should be considered as long-term average annual loadings to the stream during a time period without significant land use changes.

Caddo River watershed

47. Generalized physiographic information (Table 2), as described in the Phase I General Design Memorandum (U. S. Army Engineer District, Vicksburg 1966) for DeGray Lake and MRI Handbook information, was used in the first evaluation to determine mean annual export rates for soil, TP, and TKN. Table 3 was developed from appropriate tables and figures in the MRI Handbook.

48. The most difficult items to estimate without a thorough analysis of the topography were the overall percent slope of the land area and the slope length. The slope length was defined in the MRI Handbook as "the average distance for overland flow prior to intersecting a stream channel." No guidance was provided in the MRI Handbook to determine slope length. Therefore, 10 first-order watersheds in agricultural and

Table 2

General Description of Caddo River Watershed

Item	Agriculture	Forest
Watershed area, %	20	80
Area, ha	10,500	42,000
Slope of land, %	6	13
Slope length, m	61	46
General information	Grass and shrub cover over approx 80% of area Light to moderate grazing	Tree canopy, 70% Litter cover, 80% Managed undergrowth Medium stocked with timber

Table 3

MRI Coefficient Values Specific to Caddo River Watershed*

Coefficient	Land Use Areas	
	Agriculture	Forest
A	10,500	42,000
LS	0.9	2.6
C	0.013	0.004
S_d	0.15	0.35
DD	0.07	0.37

* From U. S. EPA (1979).

forested areas were arbitrarily selected on a topographic map of the Caddo River watershed to represent the minimum and maximum slope length and percent slope. The length and percent slope were determined for the 10 watersheds and averaged to represent the overall watershed area.

49. The land use cover factor C and sediment delivery ratio S_d were subjectively estimated. To obtain an accurate estimate of these factors would require more detailed information than normally would be available. An estimate of C may be obtained from the appropriate tables in the MRI Handbook with only a general knowledge of the watershed land use. Coefficient S_d is determined after estimating the drainage density DD , which is the ratio of stream length to watershed area within each land use classification. For the Caddo River watershed, it was estimated that approximately 70 stream kilometres drained 104 km^2 of agriculture and 96 stream kilometres drained 420 km^2 of forest. The S_d was difficult to estimate because of its ambiguous association with DD (Figure 3-10, MRI Handbook). It is assumed that the rate of sediment delivery from the land surface to a stream is dependent primarily on the number of streams per unit watershed area.

50. A more detailed description of the Caddo River watershed is given in Table 4. This information was obtained from comprehensive land use maps and soils classification data provided under contract by the Arkansas Water Resources Research Center* and by the Arkansas Soil Conservation Service. This detailed physiographic information, along with the appropriate figures and tables in the MRI Handbook and the National Atlas (USGS 1970), allowed a more thorough evaluation and subsequent selection of coefficient values representative of specific soil types and land uses (Tables 5 and 6). Subsequent determination of mean annual export rates for soil, TKN, and TP provided a comparison between the use of the generalized and detailed data to estimate the annual export rate of

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* Nix et al., op. cit.

Table 4

Detailed Description of Caddo River Watershed

Above Glenwood, Arkansas, Gage

Item	Forest	Range-land	Agri-culture	Cleared Unproductive	Urban
Watershed area, %	86	6	3	4	1
Area, ha	45,150	3150	1575	2100	525
Slope of area, %	12	3	3	3	2
Slope length, m	40	50	60	50	60
General information:					
Canopy cover, %	70	30	25	35	
Ground cover, %	85	50	30	35	

Table 5

Coefficient Values* for Determining Annual Sediment Yield

from Caddo River Watershed

Land Use-Soil Type	A	K	LS	C	S_d
Forest					
Carnasaw	18,060	0.46	0.70	0.003	0.78
Sherwood	9,030	0.26	0.40	0.003	0.52
Pickens	18,060	0.48	1.50	0.002	0.56
Rangeland					
Carnasaw	1,575	0.46	0.35	0.008	0.78
Sherwood	1,575	0.26	0.25	0.008	0.52
Agriculture					
Carnasaw	315	0.46	0.18	0.200	0.78
Pickwick	1,260	0.46	0.14	0.100	0.78
Cleared unproductive					
Sherwood	1,260	0.26	0.35	0.013	0.52
Pickens	840	0.48	0.35	0.13	0.56
Urban					
Carnasaw	105	0.46	0.30	0.010	0.78
Sherwood	367	0.26	0.35	0.010	0.52
Pickwick	53	0.46	0.20	0.010	0.78

* From U. S. EPA (1979) and USGS (1970).

Table 6

Constants* Used to Determine Water Quality Loadings from Caddo River Watershed

	Constant	Value
	R	330
	P	1.0
For estimating water quality loadings from precipitation	$\frac{Q(OR)}{Q(Pr)}$	0.15
	N_{Pr}	1.5
	b	1.0
	Temp, °C	15.8
	H	348
	Pr, mm	1408
	RH, %	70
	SVP_t	13.48
	r_n	2.0
	r_p	1.5
	C_s(NT), g/100 g	0.13
	C_s(PT), g/100 g	0.02

* From U. S. EPA (1979) and USGS (1970).

soil, TKN, and TP from the Caddo River watershed:

	Soil	TKN	TP
General physiographic data, kg/ha/yr (metric tons/yr)	723(39,929)	1.95(102)	0.23(12)
Detailed physiographic data, kg/ha/yr (metric tons/yr)	622(32,675)	1.59(84)	0.19(9.8)
Reduction, percent	14	18	17

A change of approximately 14 to 18 percent in the estimated annual export rate of soil, TKN, and TP for the Caddo River watershed was obtained using the detailed physiographic data. Hence, the development of detailed

physiographic data may not be justified in some cases, based on this one application.

51. Since the MRI method is based on the relation of water quality loadings to soil loss and subsequent suspended solids (SS) production, coefficient values for determining sediment yield must be selected with caution. In addition, the nitrogen and phosphorus concentrations in the top 30 cm of soil, C (NT) and C (PT) , must be considered critical parameters. An error of one to two orders of magnitude can be introduced, depending on the selected concentration.* Man's activities, e.g. cultivated fields, managed forests, and urban areas, may contribute significantly to nitrogen and phosphorus export from a specific watershed; therefore, C_s(NT) and C_s(PT) should be carefully evaluated. It is recommended that local SCS personnel familiar with a specific watershed be contacted for assistance in making appropriate estimates.

Sandusky River and
Honey Creek watersheds

52. Watershed characteristics required for application of the MRI method are given in Tables 7 and 8. Descriptions of watershed physiography were provided by the Buffalo District. This information was developed from analyses of high altitude photographs and topographic maps supplemented by ground truth data collection and evaluation.

53. Based on available information, the Honey Creek watershed was considered representative of the land use, relief, and soils of the Sandusky River watershed. Likewise, the percent slope and slope length for the Sandusky River and Honey Creek watersheds were considered the same for this comparison. Only the S_d and A were different (Table 9). The remaining coefficient values that were selected for the Sandusky River and Honey Creek watersheds are listed in Table 9. Only loading by erosion was considered in the computations. Rainfall data for these watersheds were not available from the Buffalo District nor the U. S. Weather Bureau.

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* The USGS based these soil nutrient concentrations on regional geomorphological soil development patterns.

Table 7

Description of Sandusky River Watershed

Item	Cropland	Woodland
Watershed area, %*	82	9
Area, ha	263,408	28,749
Slope of area, %	2	4
Slope length, m	172	307
General information	Corn, soybeans, and wheat cover 80% of the watershed area Some erosion control management Ground cover, 50%	Tree canopy, 70% Litter cover, 80% Managed undergrowth Medium stocked with timber

* The remaining 9 percent represents other land use activities and water.

Table 8

Description of Honey Creek Watershed

Item	Cropland	Woodland
Watershed area, %*	82	10
Area, ha	32,052	4096
Slope of area, %	2	4
Slope length, m	172	307
General information	Corn, soybean, and wheat cover 51%; alfalfa clover and fescue cover 31% of the watershed area Some erosion control management Ground cover, 60%	Tree canopy, 70% Litter cover, 80% Managed undergrowth Medium stocked with timber

* The remaining 8 percent represents other land use activities and water.

Table 9

MRI Coefficients Used to Determine Annual SS, TKN, and TP Export Rates from Sandusky River and Honey Creek Watersheds

MRI Coefficient	Sandusky River Watershed Cropland	Sandusky River Watershed Woodland	Honey Creek Watershed Cropland	Honey Creek Watershed Woodland
A	263,408	28,749	30,052	4096
K	0.33	0.33	0.33	0.33
LS	0.44	0.77	0.40	0.70
C	0.60	0.003	0.65	0.003
S_d	0.21	0.17	0.28	0.22
R	120	120	120	120
P	0.37	1.0	0.37	1.0
r_n	3.0	2.0	3.5	2.0
r_p	1.5	1.5	1.5	1.5
C_s(NT)	0.30	0.30	0.18	0.18
C_s(PT)	0.15	0.15	0.15	0.15

54. The mean annual export rates of SS, TKN, and TP for the Sandusky River and Honey Creek watersheds were calculated using the selected coefficient values in Table 9. Results are as follows:

Watershed	Mean Annual Export Rates, kg/ha/yr (metric tons/yr) SS	TKN	TP
Sandusky River	1824 (480,553)	11.0 (2883)	4.1 (1081)
Honey Creek	1958 (76,807)	10.6 (415)	4.4 (173)

The annual loading estimates varied primarily as a function of watershed area. Apparently, small changes in a few coefficients, i.e. S_d , r_n , r_p , C_s(NT) , and C_s(PT) , have negligible impact on the MRI results.

Discussion

55. Since the coefficients are multiplicative in the MRI equations, any error in specific coefficients is multiplied to a larger error.

Two tables in the MRI Handbook, Tables 3-10 and 4-3, provide a range of loading values for suspended solids, nutrients, and organic matter. The extreme values of each coefficient, based on available field plot data, were used by MRI to calculate the probable range shown in Tables 3-10 and 4-3 of that report. These tables illustrate the best estimate of the annual "loading range of accuracy" using this method and available supporting data. Based on the loading estimates for the Caddo River, Sandusky River, and Honey Creek watersheds, the probable range of accuracy in export estimates is presented as follows:

	Range in Export Estimates, kg/ha/yr (metric tons/yr)		
Watershed	Soil	TP	TKN
Caddo River	10-1,000 (52-52,550)	0.1-3.0 (5-158)	0.1-10 (5-525)
Sandusky River	100-5,000 (26,341-1,317,055)	2-10 (527-2634)	5-20 (1317-5628)
Honey Creek	100-5,000 (39,200-195,550)	2-10 (78-392)	5-20 (196-784)

The range of loadings for soil, TP, and TKN is so broad as to warrant omitting the MRI procedure by itself for estimating loadings to reservoirs by CE Districts.

56. Advantages. A summary of the advantages of the MRI Handbook method that are pertinent to CE planning functions is presented as follows:

a. Requires minimal field data.

b. Provides opportunity to solicit local expert assistance for selecting appropriate coefficient values.

c. Provides for the use of all available information on a specific watershed for considering appropriate coefficient values.

d. Requires minimal manpower, time, and cost to provide estimates of loadings for input into early project planning and design.

e. May provide insight into effects of changing land use by changes in coefficient values, e.g., C .

f. Is based on the USLE, which is a primary analytical tool extensively used throughout the United States by agriculturists.

57. Limitations. A summary of the limitations of the MRI method follows:

a. The USLE was developed for field-size plots, not large watersheds. The suitable aerial scale for application has not been determined.

b. The selection of USLE coefficient values is highly subjective.

c. All chemical loadings are associated with sediment yield (suspended solids). This is highly dependent on the nutrient, mineral, and organic matter content of watershed soils.

d. The USLE is comprised of terms lacking theoretical basis, e.g., sediment delivery ratio and slope length, which cannot be measured in the field for large watersheds.

e. The temporal variation of C is not documented. Seasonal variations in watershed cover are not discussed or incorporated in the MRI technique.

f. No explicit consideration is made in the USLE for runoff quantity. Terms implicitly relating to rainfall are R, K, LS, and C.

g. The seasonal effect of rainfall/runoff quantity is not considered. The R values represent the portion of the year when rainfall intensity and frequency is highest and evapotranspiration is lowest. For example, in northern Ohio, 80 percent of the erosive rainfall occurs from May through October, yet most of the runoff occurs from November through April (U. S. Army Engineer District, Buffalo 1975). In Arkansas, runoff-producing storms occur primarily from January through May (U. S. EPA 1979). As defined, most water quality export occurs during these months and not throughout the year, as MRI's estimated annual export rate suggests.

h. A variation of at least 10 to 100 times can be introduced in the annual loading estimates of total nitrogen and total phosphorus if $C_s(NT)$ and $C_s(PT)$ are in error for watershed subarea i.

National Eutrophication Survey

58. The NES technique consists of regionalized regression equations incorporating three general categories of land use: forest, agriculture, and urban. The rationale and data used to develop this nonpoint source loading technique are thoroughly described in the NES Handbook

(Omernik 1977). Unlike the MRI methodology, consideration of annual sediment production, i.e., suspended solids, is not included in this procedure.

59. The NES regional equations were used to estimate the mean annual concentrations of orthophosphorus and total phosphorus and inorganic and total nitrogen (TN) in the Caddo River, Sandusky River, and Honey Creek. The only data required were the percentage of each land use (Table 10), and mean annual flow for each stream.

Table 10

Percentage Land Use Composition of Caddo River, Sandusky River, and Honey Creek Watersheds

Watershed	Agriculture	Forest	Urban
Caddo River	3	86	1
Sandusky River	82	9	6
Honey Creek	82	10	5

60. The estimated standard error σ for water quality data representative of the Caddo River, Sandusky River, and Honey Creek watersheds was selected from Figures 24-27 in the NES Handbook. The suggested range of standard error (Table 11) for each geographical area was also used to compare the respective range of estimated loading values for the water quality parameters. The selection of a standard error is subjective; it is based on the assumption that a given watershed would be similar to the average watershed for that specific geographical region. In developing the regional regression equations, the NES team assumed that they were sampling from a normal distribution of watersheds without point source pollution. However, only 928 of the 4000 NES tributary sites met this criterion. The broad range of standard error, as specified for each geographical region of the United States, is illustrative of the water quality variability found within each region.

61. The mean annual nutrient concentrations (Table 12) were similar to the NES results, presented in Figures 3 and 4 of the NES Handbook, for the estimated TP concentration in >75 percent forested and

Table 11

Estimated Standard Error σ (mg/ℓ) and Suggested Range* of Selected Water Quality Parameters for Caddo River, Sandusky River, and Honey Creek

Water Quality Parameter	Caddo River		Sandusky River		Honey Creek	
	σ	Range	σ	Range	σ	Range
Total phosphorus	0.1	-0.5 to 0.5	0.1	-0.5 to 0.5	0.1	-0.5 to 0.5
Ortho-phosphorus	0.3	-0.5 to 0.5	-0.4	-0.5 to 0.5	-0.4	-0.5 to 0.5
Total nitrogen	-0.2	-0.5 to 0.5	1.0	0.5 to 1.0	0.8	0.5 to 1.0
Inorganic nitrogen	-0.5	-1.0 to -0.5	0.2	-0.5 to 0.5	0.1	-0.5 to 0.5

* NES Handbook (Omernik 1977).

Table 12

Comparison of Annual TP and TKN Concentrations with NES Regression Analyses

Watershed	TP, mg/ℓ		TKN,* mg/ℓ	
	Estimate	Range	Estimate	Range
Caddo River	0.02	(0.01-0.03)	0.41	(0.36-0.59)
Sandusky River	0.12	(0.07-0.12)	2.3	(1.8-4.7)
Honey Creek	0.11	(0.07-0.14)	2.5	(1.0-4.3)
NES (>75% forest)	0.02		0.52	
NES (>75% agriculture)	0.14		1.13	

* TKN = TN - (NO_3-N + NO_2-N).

agricultural watersheds. Good agreement was also observed for TKN (equivalent) in the forested watersheds; however, the estimated TKN (equivalent) in the agricultural watersheds was twice that estimated by NES analysis for similar watersheds. Two reasons for the overestimation may be considered: (a) the seasonal loading patterns of nitrogen cannot be examined as described in the NES Handbook since the regional relationships were developed on only a 1-year data set; and (b) nitrogen loading depends significantly on time of year, quantity and method of fertilizer applications, and tilling operations.

62. Maps, presented in Figures 25-28 of the NES Handbook, were developed to assist in selecting an appropriate standard error representative of the study regions. However, they were not sufficiently detailed to represent all basins within a region. Only in those regions where NES data were concentrated was it possible to estimate a reasonable standard error. This may explain why the range of loadings for phosphorus and nitrogen as estimated for the Caddo River was so close to the regional loading means; whereas, the range of loadings for the Honey Creek and Sandusky River watersheds was not close to the regional loading means.

63. Table 13 shows the estimated average annual export rate of TP and TKN for the Caddo River, Sandusky River, and Honey Creek watersheds. Significantly higher nutrient loadings are estimated from the

Table 13

Comparison of Annual Water Quality Export Rates Using NES Regional Analysis*

	TP				TKN**			
	kg/ha/yr		metric tons/yr		kg/ha/yr		metric tons/yr	
Watershed	Avg	Range	Avg	Range	Avg	Range	Avg	Range
Caddo River	0.17	(0.11-0.23)	9	(5-14)	3.5	(3.1-5.1)	186	(163-268)
Sandusky River	0.77	(0.45-0.77)	188	(110-188)	15	(12-30)	3605	(2821-7366)
Honey Creek	0.48	(0.33-0.62)	19	(12-24)	11	(4-19)	434	(173-746)

* Range assuming recommended lower and upper limits of standard error. The NES computed ranges are listed in parentheses, i.e., based on ±1 standard error.

** TKN = TN - (NO_3-N + NO_2-N).

agricultural watersheds than from the forested watersheds. The computed range (in parentheses) was based on the NES's standard error for the regions.

64. In comparison to the MRI analysis (paragraph 56), a slightly lower average and a narrower range in annual TP export estimates were computed using the NES technique. However, the annual TKN export estimates for the MRI and NES methods were quite similar. From these results, both techniques compared favorably for the forested Caddo River watershed only.

65. It would appear that the NES analysis provided a better planning tool than the MRI method for estimating loadings because it is based on actual data from watersheds throughout the United States. However, the NES study specified that the regional regression equations were applicable only to the data used in their analyses and the specific time covered by the respective sampling period. Since the data were not flow-weighted and represent only 1 year of monthly data collection for each region, the mean annual nutrient concentration expressed for each watershed in the study does not relate to year-to-year, month-to-month, or storm-to-storm variability (McDowell and Omernik 1979). Subsequent changes in land use since completion of the NES sampling program could greatly alter the coefficient values and land use factor composition within each regionalized equation. Finally, there was no empirical basis for the NES loading relationships as was purported by the MRI method, which uses the USLE. The NES procedure would appear to be most reliable for large, geographically similar watersheds as shown in Figures 25-28 of the NES Handbook. For these reasons and those listed below, CE application of this loading technique for planning is not recommended except when applied to watersheds in geographical areas where a large number of NES watersheds exist.

66. Advantages. Advantages of the NES method are the following:

- a. Only percentage land use composition of a watershed and mean annual flow are required to apply the technique.
- b. Required figures and tables are provided in the NES Handbook.

c. Provision is made for computing a range in mean annual loadings of total nitrogen and inorganic nitrogen.

d. Very little cost and effort are required to obtain loading values.

e. There is no limit to the size of watershed for application of this loading technique.

67. Limitations. The limitations of the NES method are as follows:

a. All variability between watersheds within a region is expressed as percentage land use differences. Furthermore, heavy reliance is placed on available aerial photography and maps to delineate land uses. Many sites do not have this information available.

b. Agricultural and urban land uses are not differentiated relative to nonpoint source loadings of nutrients.

c. A historical flow record is required to obtain a realistic mean annual flow without being biased toward wet- or dry-year periods.

d. Regionalized equations may have shown correlations between existing land use and water quality concentration patterns during the NES study. No theoretical basis exists for predicting loadings if a change in land use or water quality concentration occurred since the NES completed their sampling program.

e. Large areas of the United States were not included in the study, e.g., southwest and coastal plains of the southeast.

f. Only nitrogen and phosphorus loadings were included in the NES analysis.

$\bar{Q}*\bar{C}$, $\overline{QC}$, and FI Instream Techniques

$\bar{Q}*\bar{C}$ technique

68. Instream techniques have been used extensively within CE Districts to compute annual nonpoint source water quality loadings to reservoirs. The $\bar{Q}*\bar{C}$ method has been found to be predominant based upon a telephone survey of each CE District. Since most instream data collection programs have been conducted in cooperation with USGS and have utilized USGS procedures, the majority of the available data reflect the prevalent flow and stream water quality conditions associated with base flow. Moreover, surface water quality data for these streams have been

based on weekly, biweekly, or monthly grab samples. Water quality data representative of elevated flow conditions, i.e., incorporating hydrograph sampling, are not adequately considered in most routine sampling programs to determine the influence of elevated flow on constituent export rates. Consequently, suspended solids and nutrient loadings based on historical data are biased toward low-flow conditions. Similar conclusions were made by a previous investigation (Johnson et al. 1976). This technique is most appropriate for estimating annual water quality loadings of conservative constituents, e.g., pH, sodium, and potassium, where only data from routine sampling programs are available.

$\overline{QC}$ technique

69. The $\overline{QC}$ technique has been used for determining the annual export rate of both flow-dependent and flow-independent water quality constituents. However, application of this technique does not improve the export rate estimates for those constituents, e.g., TKN, associated with organic components of runoff unless the data are representative of elevated and base flow conditions. The composition and quantity of particulate and dissolved organic components in runoff are influenced by many factors, including season; storm intensity, duration, and frequency; and degree of decomposition of the organic material (Lystrom et al. 1978, Johnson et al. 1976, Fisher et al. 1968, Biggar and Corey 1969). The relative influence of these factors on the computed annual loading estimates depends on the number of samples and period of time over which the samples are collected and analyzed. To lessen the influence of these factors, sampling is required to adequately represent the seasonal differences and characteristic storm patterns in a specific watershed. Consequently, the design of the sampling program must consider the frequency of occurrence of elevated flows and associated water quality loadings prior to applying this technique.

FI technique

70. The FI technique (Fisher et al. 1968) is essentially a stream water quality rating method. It is based on identifying the frequency of occurrence of different flows and determining the water quality loading rate for specified flow intervals. The technique uses instantaneous

flow and water quality data for computing the flow-weighted, mean loading rates within selected flow intervals. The impact of infrequent high- and low-flow conditions and associated constituent concentrations on the estimated water quality loading rate is reduced significantly by weighting the computed export rate by the frequency of occurrence of each flow value in the historical flow record. Though the nature and amount of field data required for application will vary from project to project, elevated and low flow conditions must be represented. Consequently, historical data and/or additional field sampling must include samples obtained over a wide range of streamflow. A cost-effective instream sampling program should be designed to sample throughout selected flow hydrographs during different seasons of the year. Guidance on sampling frequencies is provided by Johnson (1979). Data should include either discrete concentration measurements and daily flow records or discrete concentration measurements and simultaneous flow measurements. Appropriate application of the instream techniques depends on: (a) the quality and extent of the historical flow and water quality data, (b) the adequate representation in the data set of low and elevated streamflow conditions, and (c) the amount of funds and time available to obtain field data, if sufficient data do not exist for specific projects. Where seasonal changes may influence the export rate of selected chemical constituents, e.g., orthophosphate and nitrite- and nitrate-nitrogen, a better estimate of the annual export rate is obtained by grouping the data and computing seasonal export rates.

Discussion

71. The influence of elevated versus low flows on the estimated loading rates for the Caddo River is shown in Table 14. Approximately 200 samples from nine storm flow hydrographs on the Caddo River were analyzed. The storms represented winter, summer, and fall seasons. High- and low-flow data were separated arbitrarily into two groups for analysis, i.e., data above or below the 26-year mean daily flow of 14 cu m/sec. Approximately 70 percent of the 200 samples were representative of flows less than 14 cu m/sec. The flow frequency, as characterized by nine flow hydrographs, corresponded to the 26-year flow record for the

Table 14

Comparison of Water Quality Export Rates Using the Instream Methods at Various Flow Conditions for Caddo River, 1975-1977

Loading Technique	Flow State	Export Rate, kg/ha/yr		
		Suspended Solids*	TKN**	TP†
$\bar{Q}*\bar{C}$	Elevated flow	471 ± 202 (43%)††	11 ± 4 (40%)	0.5 ± 0.3 (51%)
	Low flow	34 ± 22 (65%)	1 ± 0.3 (35%)	0.02 ± 0.004 (20%)
	All flow	358 ± 81 (23%)	8 ± 0.9 (11%)	0.37 ± 0.06 (16%)
$\overline{QC}$	Elevated flow	1540 ± 430 (28%)	18 ± 14 (77%)	1 ± 0.4 (41%)
	Low flow	36 ± 25 (68%)	1 ± 0.6 (70%)	0.02 ± 0.004 (15%)
	All flow	675 ± 104 (15%)	10 ± 1.7 (17%)	0.65 ± 0.15 (23%)
FI @ 5 cu m/sec	Elevated flow	NA	NA	NA
	Low flow	NA	NA	NA
	All flow	305 ± 64 (21%)	5.3 ± 0.5 (9%)	0.36 ± 0.04 (11%)
FI @ 2 cu m/sec	Elevated flow	NA	NA	NA
	Low flow	NA	NA	NA
	All flow	258 ± 50 (19%)	5 ± 0.4 (8%)	0.32 ± 0.03 (9%)

Note: Gage at Glenwood, Arkansas, Highway 84 bridge.
* No. of samples: 67 elevated flow, 118 low flow, 195 all flow and concentration.
** No. of samples: 67 elevated flow, 107 low flow, 174 all flow and concentration.
† No. of samples: 67 elevated flow, 157 low flow, 224 all flow and concentration.
†† One standard error expressed as percent.

Glenwood gage. Approximately 80 percent of the measured flows, or 7680 samples, were below 14 cu m/sec.

72. The standard errors of the estimates were computed, assuming that statistically different loading relationships existed for SS, TKN, and TP at flows less than or greater than 14 cu m/sec. Only the $\bar{Q}*\bar{C}$ and $\overline{QC}$ loading techniques were compared, since the FI technique, by definition, is not applicable to this type of comparison. The importance of elevated flows in exporting water quality constituents was clearly illustrated by comparing the export rates and standard error (Table 14). The highest loading of SS, TKN, and TP occurred during flows >14 cu m/sec. Moreover, the SS export rate computed using the $\overline{QC}$ technique was approximately three times the export rate computed using the $\bar{Q}*\bar{C}$ method. Only after combining the low and elevated flow data were the estimated loading and percent standard errors significantly improved for both methods. These results indicate a need for a representative data set incorporating low and elevated flow conditions at their statistically normal frequency of occurrence, if the $\bar{Q}*\bar{C}$ and $\overline{QC}$ techniques are to be used.

73. The estimated mean annual export rates and standard error of the estimates for SS, TKN, and TP for the Caddo River, Sandusky, and Honey Creek watersheds (Figure 5) were compared. The number of flow and water quality samples used for this analysis is listed in Table 15. The mean annual water quality export rates computed by the $\bar{Q}*\bar{C}$ and $\overline{QC}$ techniques varied within only a factor of two to three for each watershed (Figure 5). However, when the water quality export rates were

Table 15

Number of Samples Analyzed Using the Instream Loading Techniques

Watersheds	Flow	Suspended Solids	Total Kjeldahl Nitrogen	Total Phosphorus
Caddo River	226	195	174	224
Sandusky River	1337	1253	194	1289
Honey Creek	1202	1181	276	1191

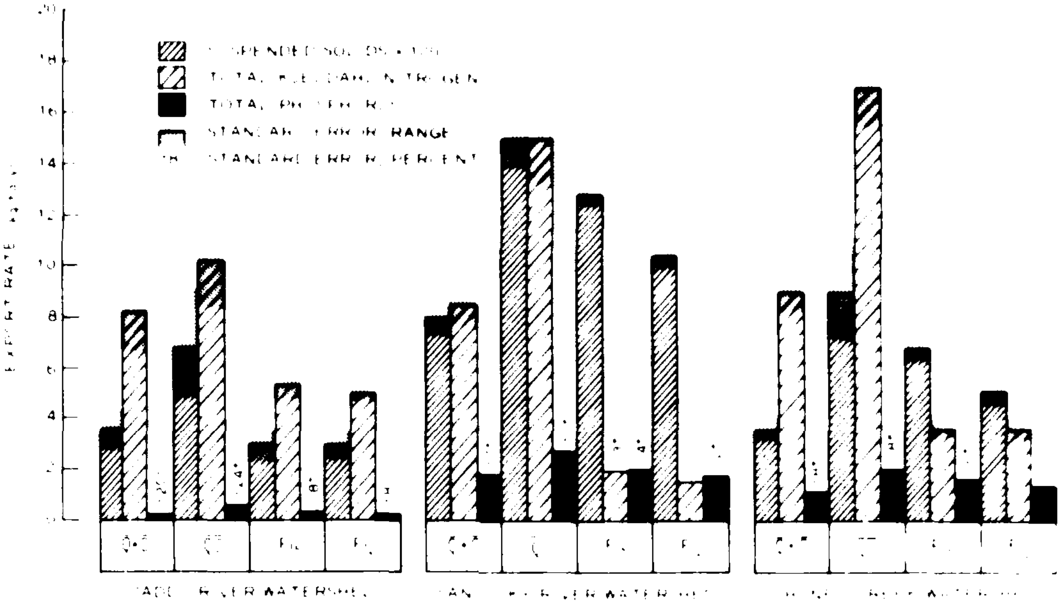

Figure 5. Comparison of estimated mean annual export rates using instream data

flow-weighted and adjusted for their probability of occurrence (FI technique), the estimated annual export rate and standard error of estimate were reduced significantly. Moreover, the influence of infrequent elevated flows and subsequent high water quality constituent concentrations on computed annual export rates (Figure 5, FI_5 and FI_2) was reduced significantly compared to the QC technique.

74. The FI technique yielded a twofold reduction in the computed annual export rate for SS, TKN, and TP as compared with the other instream loading methods (Table 14 and Figure 5). Also, the standard error of the estimate was reduced to 19 to 21 percent for SS and 8 to 11 percent for TKN and TP. Similar results were reported for the tributaries of Lake Erie by the U. S. Army Engineer District, Buffalo (1975). Furthermore, there was virtually no change in the computed annual export rate and error of the estimate by using a 2-cu-m/sec flow interval rather than the 5-cu-m/sec interval (Table 14 and Figure 5).

75. The export rates of SS, TKN, and TP from the Sandusky River

and Honey Creek watersheds (Figure 5) were nearly identical. Estimated SS and TP export rates using the FI method were similar to the respective export rates computed by the $\bar{Q}*\bar{C}$ and $\overline{QC}$ methods. An adequate number of samples (Table 15) had been analyzed for these rivers to statistically represent the natural frequency of occurrence for low- and elevated-flow conditions. The TKN export rate, as determined by the FI method, was much higher for Honey Creek than for the Sandusky River. Moreover, the export rate of SS from the Sandusky River watershed was more than double the rate from the Honey Creek watershed. Explanations for these differences may include any number of factors: unique point sources, land use and land use management differences in the watersheds, soil type differences, and areal variation of rainfall in the watersheds. In constrast, the annual export rates of TP from the two agricultural watersheds were nearly identical.

76. The export rates of TP, SS, and TKN using the FI analysis (Figure 5) were similar to previous research comparing runoff from forested and agricultural watersheds (True 1976, Fisher et al. 1968, and Timmons, Burwell, and Hoit 1973). The estimated annual export rate of TP was 10 times lower for the Caddo River watershed than for either the Sandusky River or Honey Creek watershed. The SS export rate from the Honey Creek watershed was twice the rate from the Caddo River watershed. The TKN export from the forested Caddo River watershed was twice the rate of either the agricultural Sandusky River or Honey Creek watersheds.

77. The appropriate application of the instream techniques for estimating mean annual export rates depends on: the quality and extent of the historical flow and water quality data; the adequate representation in the data set of low and elevated streamflow conditions; and the amount of time and funds available to obtain additional data for specific projects. The data used for evaluating these loading techniques represented very extensive sampling programs. One objective of the sampling program for each watershed was to obtain sufficient instantaneous flow and water quality data to permit water quality constituent loading analyses. Unfortunately, most of the flow records from gaging stations throughout the United States report mean daily flows, whereas water

quality data represent instantaneous measurements. The estimated mean annual export rate using available data should not bias the estimate to an unacceptable level as long as high flows are represented (U. S. Army Engineer District, Buffalo 1975). However, this estimate could be misleading only if the mean daily flows significantly underestimate water quality loadings occurring at intervals more frequent than daily, i.e., during storm events (Westerdahl, Perrier, and Nix 1977).

78. It is difficult to specify the adequacy of a data set. The respective elevated- and low-flow conditions represented by the data should be consistent with the intended application. In the FI analysis, it was assumed that storm events were most important in the loading of water quality constituents from the watershed. For example, the approximately 200 samples (Table 15) analyzed for the Caddo River watershed included 9 storm hydrographs that represent winter, summer, and fall storms. Since most of the SS, TKN, and TP loadings occurred at elevated flow (Table 14), the data were considered representative of the water quality loadings from all watershed sources.

79. These instream techniques are not appropriate for computing loading estimates for periods other than the period of record being analyzed. However, the FI method was considered the most reasonable technique based on advantages and limitations listed in Table 16. Generally, any instream technique that incorporates the probability of occurrence for specific flows and water quality concentrations would be most appropriate for estimating mean annual water quality export rates for the time period associated with the data.

General Discussion

80. Mean annual loadings of SS, TKN, and TP for the Caddo River, Sandusky River, and Honey Creek watersheds are summarized in Table 17. The MRI method provides the broadest range of loadings for SS, TKN, and TP. Selection of each MRI coefficient involves some degree of subjectivity. Any errors made in each coefficient selection are multiplied during computations in solving the soil loss equation. Moreover, TP

Table 16

Characteristic Advantages and Limitations

of Instream Techniques

Advantages	Limitations
Average Flow, Average Concentration	
Mean annual flow and water quality constituent concentrations are computed using all available historical data for the stream, e.g., mean daily flows and discrete water quality measurements.	Water quality constituent export rate is assumed to be flow independent.
Minimal manpower, time, and cost are required to provide estimates of loading for input into early project planning and design.	
Flow-Weighted Concentration	
Only the historical flow data are required at the time samples for water quality were analyzed. Any additional field studies would be limited to sampling at different flow rates to obtain these data.	Water quality constituents are assumed to be flow dependent.
Minimal manpower, time, and cost are required to provide estimates of loadings for input into early project planning and design.	Frequency of elevated and low flows is not a consideration. Consequently, the mean annual loading rate may either be higher or lower than the actual loading rate for the stream.
Flow Interval	
This is valid for most flow-dependent and flow-independent water quality constituents.	Data bases are required that include either discrete concentration measurements and the daily flow record or discrete concentration measurements and simultaneous flow measurements.
Limited data that represent storm hydrograph sampling characteristic of different storm intensities and duration throughout a year are adequate for computing realistic annual water quality loadings from a watershed.	Considerable data representative of seasonal loadings are required for those constituents influenced by seasonal changes, e.g., orthophosphate and nitrite- and nitrate-nitrogen. The annual export rate of these constituents can be determined by grouping the data by season and using the FI method to compute an export rate for each season.
	Though selection of flow interval size is arbitrary, considerable effort may be required to group the data accordingly. This is especially significant if the data base is not computerized.

Table 17

Comparison of Mean Annual Loadings of SS, TKN, and TP for the Caddo River, Sandusky River, and Honey Creek Watersheds

Loading Technique	Mean Annual Loading, metric tons/yr SS	TKN	TP
Caddo River			
MRI (No.1)	39,929	102	12
(No.2)	32,675	84	10
Range	52-52,550	5-158	5-525
NES	--	215 (±24%)	10 (±50%)
$\bar{Q}*\bar{C}$	18,770 (±23%)	418 (±18%)	19 (±19%)
$\overline{QC}$	35,448 (±30%)	536 (±17%)	34 (±24%)
FI @ 5 cu m/sec	16,036 (±21%)	280 (±9%)	19 (±8%)
FI @ 2 cu m/sec	13,523 (±20%)	263 (±7%)	17 (±8%)
Sandusky River			
MRI	480,553	2883	1081
Range	26,341-1,317,055	1317-5628	527-2634
NES	--	7527 (±11%)	150 (+30%)
$\bar{Q}*\bar{C}$	209,675 (±9%)	2240 (±11%)	464 (±7%)
$\overline{QC}$	396,097 (±8%)	3979 (±11%)	749 (±7%)
FI @ 5 cu m/sec	337,782 (±4%)	520 (±3%)	632 (±2%)
FI @ 2 cu m/sec	273,420 (±5%)	395 (±3%)	506 (±2%)
Honey Creek			
MRI	76,807	415	173
Range	39,200-195,550	196-784	78-392
NES	--	492 (±62%)	18 (±33%)
$\bar{Q}*\bar{C}$	13,923 (±10%)	353 (±9%)	45 (±8%)
$\overline{QC}$	34,721 (±17%)	666 (±9%)	83 (±8%)
FI @ 5 cu m/sec	26,408 (±9%)	142 (±8%)	67 (±6%)
FI @ 2 cu m/sec	19,907 (±12%)	142 (±7%)	57 (±7%)

and TKN export rates are subject to the error of the SS loading estimate as well as the range of values for $C_s(PT)$ and $C_s(NT)$. Most importantly, however, the MRI technique requires that the user be familiar with watershed land use, soil, and hydrologic characteristics. The MRI procedure does offer a technique for estimating changes in water quality loadings as a function of future changes in land use.

81. The NES method of regional regression analysis has only limited use for CE application. Only those CE project areas within the general vicinity of the NES study sites can be considered appropriate. Loading estimates should be obtained by selecting the most appropriate standard deviation represented in Figures 24-28 of the NES Handbook for a specific watershed.

82. Of the three instream techniques, the FI method is recommended. Though historical flow and water quality records are desired, analysis of even limited seasonal data can be performed with the technique. Interval size has only a slight effect on the computed annual loadings and standard error of the estimate (Table 17).

PART V: IMPLICATIONS FOR ASSESSING RESERVOIR EUTROPHICATION

Introduction

83. Throughout project planning and during the operation of existing projects, recurring questions are raised concerning the trophic status of a reservoir. Vollenweider (1968) proposed one of the first methods based on a correlation of total annual point and nonpoint source loadings versus lake response rather than on internal lake processes. However, this method was developed using a data base primarily from northern, temperate natural lakes that, therefore, is not applicable for most CE reservoirs. Several investigators, e.g. Shannon and Brezonik (1972), Dillon (1974, 1975), Dillon and Rigler (1974), and Larsen and Mercier (1976), attempted to develop better techniques or to modify Vollenweider's methodology. These methods, also based on the use of external nutrient loadings, i.e., phosphorus, provide an evaluation of the eutrophication state of existing lakes.

84. The TP loadings, estimated by each technique in this study, were used to illustrate what could happen when the loading estimates are used to assess reservoir eutrophication. The eutrophication assessment method proposed by Larsen and Mercier (1976) was selected to compare the effects of various annual loading estimates. This method uses mean annual phosphorus loading, net annual phosphorus sedimentation, and general reservoir morphometric and hydraulic considerations to provide an estimate of trophic status, e.g., oligotrophic, mesotrophic, and eutrophic. However, many assumptions and limitations must be recognized in order that this or similar procedures may be used and interpreted appropriately. Some of these were summarized by Larsen and Mercier (1976) and Dillon (1974). The various methods make the following assumptions:

- a. Phosphorus concentration is an indication of lake trophic state. Phosphorus is considered to be the limiting nutrient.
- b. Rate of water inflow and outflow is steady and equal.

c. The lake is an instantaneously well-mixed system; i.e., inflows are instantaneously dispersed throughout the lake.

d. There is a net loss of phosphorus to the sediment annually.

e. Sedimentation rates are at steady-state in the lake.

f. Outflow water constituent concentrations are representative of the mean concentrations in the lake.

g. With a change in loading rate, the lake biomass will increase or decrease accordingly.

Application and Evaluation of Annual Loading Techniques for Assessing Reservoir Trophic State

85. Of the three watersheds studied, only the data set for the Caddo River contained the requisite data. Therefore, it was selected for the comparative evaluation.

86. To estimate the trophic status of DeGray Lake, the Larsen and Mercier (1976) relation was used:

$$P = \frac{P_\infty}{1 - R_{exp}} \tag{20}$$

where

P = phosphorus concentration in the reservoir, mg/ℓ

P_∞ = incoming phosphorus concentration at steady-state, mg/ℓ

R_{exp} = empirically determined phosphorus retention coefficient, i.e.,

$$R_{exp} = 0.854 - 0.142 \ln q_s \tag{21}$$

q_s = areal hydraulic load, dimensionless, i.e,

$$q_s = \bar{Z} \times \sigma_w \tag{22}$$

$\bar{Z}$ = mean reservoir depth, m (13.3 m for DeGray Lake)

σ_w = theoretical hydraulic washout coefficient.

The theoretical hydraulic washout coefficient is:

$$\sigma_w = \frac{1}{\Upsilon_w} \tag{23}$$

where

Υ_w = hydraulic residence time, i.e.,

$$\Upsilon_w = \frac{\text{reservoir volume}}{\text{annual water discharge}} = \frac{V_w}{Q} \tag{24}$$

87. To determine the annual water discharge from DeGray Lake, a 10-year flow record (1966-1976) for Glenwood, Arkansas, was used for a first approximation. From a previous study, which predicted the annual inflow to DeGray Lake (Perrier and Ford 1978), a correction of 30 percent on an area basis was required to incorporate the drainage area between Glenwood, Arkansas, and the Highway 84 gage. The latter stream gage was assumed to be the inflow to DeGray Lake. Therefore, the annual discharge rate from DeGray Lake was estimated as 590×10^6 cu m/yr. Using the TP average annual loading in Table 17, the incoming phosphorus concentration at steady-state was

$$P_\infty = \frac{\text{annual loading}}{\text{yearly water discharge}} \tag{25}$$

Table 18 lists the estimated inflow phosphorus concentrations to DeGray Lake using the Highway 84 gage data. Equation 21 was used to compute the phosphorus retention coefficient as follows:

$$R_{exp} = 0.854 - 0.142 \ln q_s$$

where

$$q_s = \frac{\bar{Z}}{\Upsilon_w} = \frac{\bar{Z} \times Q}{V_w} = 11.04 \text{ cu m/yr (Highway 84 gage)}$$

$$\ln q_s = 2.4$$

and

$$R_{exp} = 0.51$$

88. According to Figure 1 in the Larsen and Mercier (1976) study, the MRI and NES methods result in DeGray Lake being classified as either oligotrophic, mesotrophic, or eutrophic based on the MRI range and the NES mean annual TP loading. The three instream methods place DeGray Lake in the mesotrophic to eutrophic state, definitely not oligotrophic (Table 18). DeGray Lake is most closely classified as mesotrophic based on EPA's interpretation of data obtained from the NES sampling program. This application emphasizes the extreme caution that must be used by CE Districts when applying Vollenweider-type analyses to estimate the trophic status of a reservoir based on annual phosphorus loading estimates.

Table 18

Estimated Mean Annual Inflow Phosphorus Concentration to DeGray Lake

Loading Technique	P_∞ , μg/ℓ Glenwood, Ark.	Highway 84	Predicted Trophic State
MRI	22	29	Oligotrophic, mesotrophic, or eutrophic
Range	11 - 275	11 - 275	
NES	26 ± 13*	34 ± 17	Oligotrophic, mesotrophic, or eutrophic
$\bar{Q}^*\bar{C}$	42 ± 8*	55 ± 11	Mesotrophic
$\overline{QC}$	75 ± 18*	97 ± 23	Eutrophic
FI @ 5 cu m/sec	42 ± 3*	55 ± 4	Mesotrophic

* ± 1 standard error, μg/ℓ .

PART VI: CONCLUSIONS AND RECOMMENDATIONS

89. Conclusions and recommendations based on the results of this study are as follows:

- a. The MRI procedure for suspended solids (USLE) is based on theoretical input requirements that are virtually impossible to quantify for any watershed perhaps larger than a farm field. Similarly, $C_s(NT)$ and $C_s(PT)$ are extremely important in the loading calculations for nitrogen and phosphorus. However, they are not easily quantified for specific watersheds because of the heterogeneous soil composition and land use patterns. This technique does allow the planner to become familiar with watershed physiography and hydrology, which enables him to better interpret loading estimates for a specific reservoir. Consequently, the MRI procedure is recommended for those projects with little or no existing streamflow and water quality data, and where a projection of future loadings resulting from changing land use is required.
- b. The NES procedure uses regional regression equations that were developed using results from a nationwide field study that incorporated only 1 year of data collection at monthly intervals for each sampling location. The equations are at best applicable to geographical areas where a significant number of NES sampling locations exist. Therefore, the NES method only has limited application to CE projects within the vicinity of the watersheds included in their survey. It is not recommended for general use.
- c. The average flow, average concentration $\bar{Q}*\bar{C}$ method is only applicable to water quality constituents that maintain fairly constant concentrations through the range of streamflow. Consequently, it is not recommended for SS, TKN, and TP.
- d. The applicability of the flow-weighted concentration $\overline{QC}$ loading technique depends heavily on the degree to which the data for a specific watershed are representative of the normal range of flow and water quality concentrations. This technique is not recommended for general use.
- e. The flow interval (FI) technique, which incorporates the probability of occurrence for given flow and water quality concentration, is a statistically valid method for analyzing existing instream data. However, those water quality constituents whose loading is dependent on season and flow require sufficient data to compute the short-term or seasonal loadings and sum them to obtain an estimate of the annual loading. This technique is recommended for analysis of instream data.

f. Field sampling programs to obtain an instream data set for estimating water quality loadings should include simultaneous measurement of flow and quality over a wide range of streamflow conditions. In addition to periodic baseflow sampling, selected storm hydrographs should be sampled during different seasons of the year. Results of the Lake Erie wastewater management study (U. S. Army Engineer District, Buffalo 1975) and previous investigations on the Caddo River (Westerdahl, Perrier, and Nix 1977, Westerdahl et al. 1975) clearly illustrate the importance of elevated flow sampling. The required sampling frequency will depend on the hydrologic characteristics of the watershed and the magnitude and duration of the storm. Samples generally should be taken at 1- to 2-hr intervals throughout the ascending limb and peak of the hydrograph. Sampling frequency normally can be reduced for the descending limb of the hydrograph. After the hydrograph is recorded, cost of sample analysis can be reduced by selecting samples representative of various portions of the storm hydrograph and discarding excess samples. Normally, about 10 samples per storm are required with emphasis placed on the ascending limb and peak flow portions of the hydrograph. Automatic samplers that are activated by changes in flow velocity or river stage are recommended when extensive sampling is required.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Westerdahl, Howard E
 Evaluation of techniques to estimate annual water quality loadings to reservoirs / by Howard E. Westerdahl ... [et al.]. (Environmental Laboratory. U.S. Army Engineer Waterways Experiment Station) ; prepared for Office, Chief of Engineers, U.S. Army -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1981.
 61 p. : ill. ; 27 cm. -- (Technical report / U.S. Army Engineer Waterways Experiment Station ; E-81-1)
 Cover title.
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 1. Evaluation. 2. Lakes. 3. Land use. 4. Nitrogen. 5. Phosphorus. 6. Reservoirs. 7. Suspended solids. 8. Water quality. 9. Watersheds. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. United States. Army Engineer Waterways Experiment Station. Environmental Laboratory. III. Title. IV. Series: Technical report (United States. Army Engineer Waterways Experiment Station) ; E-81-1.
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